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(Robert Armstrong, Principal Investigator)

This report describes the results of an experimental investigation of a coupled resonance detection scheme with intended applications to optical sensors (in particular bio-sensors). The work exploits recent advances in resonant sensor and enhanced optical coupling technologies. Multiplicative enhancement of optical gain is achieved through a coupled resonator configuration involving whispering-gallery modes (WGM's) in a dielectric microsphere coupled to Surface-Enhanced-Raman Scattering (SERS) emission from analyte-doped metal nanoparticles. Evanescent coupling of WGM and SERS emissions provides a significant increase in resonator output as compared with conventional far-field sensors.

Brief Statement of Basic Concept:

In many scenarios involving biological or other threat molecules, there is a vital need for a reliable, rapid optical sensor. Exploiting the fingerprint characteristics of Raman scattering, we have developed a Raman-based optical sensor to accomplish this objective. SERS emission from analyte molecules adsorbed on metal nanoparticles provides large optical gain, while simultaneously suppressing the unwanted effects of non-adsorbed species. If the metal nanoparticles are adsorbed on the exterior surface of a dielectric micro-cavity, SERS emissions are efficiently coupled to micro-cavity WGM's, providing further (multiplicative) gain. The resulting total gain can be extremely large. Finally, conventional, far-field coupling the Raman emitters, typically very inefficient, is replaced by near-field evanescent coupling. Benefits of this scheme include far greater coupling efficiency (i.e., signal levels dramatically improved over conventional far-field coupling schemes), and greater simplicity in the coupling and signal collection experimental stages.

Description of Work

Evanescent coupling arises from the same fundamental optical process that is responsible for the well-known phenomenon of total internal reflection. For incident angles greater than the critical angle, the transmitted field becomes exponentially damped, decaying with a characteristic length scale of the order of the optical wavelength; for visible light, this scale is of the order of a few hundred nm. Evanescent light may be produced by several

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14. ABSTRACT

Nano-scale sub-wavelength plasmon resonators will be fabricated by e-beam lithography, and evaluated to determine their suitability for solid-state quantum computing and other applications. The goal of the spectroscopic studies is to carry out spectroscopic, and especially nonlinear spectroscopic, studies of fractal/microcavity (including PBG cavities) composites, and to assess the effect of metal nanoparticle quantum well structures on the spectra. There will be an assessment of the potential of such structures in the fabrication of ultra-sensitive molecular, and particularly biochemical media. These experiments will be compared with similar experiments in which chemical techniques are used to fabricate composites.

15. SUBJECT TERMS
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techniques including prism and tapered fiber coupling schemes. In the experiments described here, we employ a prism coupler. Although tapered fiber couplers provide somewhat greater coupling efficiency (by a factor of approximately 2), the simplicity of prism couplers makes them preferable in these initial experiments.

The experimental arrangement is sketched in **Fig. 1**; light from a cw laser (a 3 mW HeNe is used in the experiments reported here) is focused through the interior of a glass prism onto its hypotenuse face at an angle greater then the critical angle, thereby emerging as evanescent light in the region beyond. A 50 micron radius glass microsphere is positioned in the evanescent region by an x-y micro-positioning translator (parallel to the hypotenuse face) and by a z nano-positioning translator (perpendicular to the hypotenuse face). For values of z in the few-hundred nm range and x-y positioning accuracy of a few microns, evanescent coupling occurs, signaled by the presence of strong WGM resonant emissions visible in light directly emitted by the microcavity The emitted light is analyzed by a grating spectrograph and detected with a CCD detector.

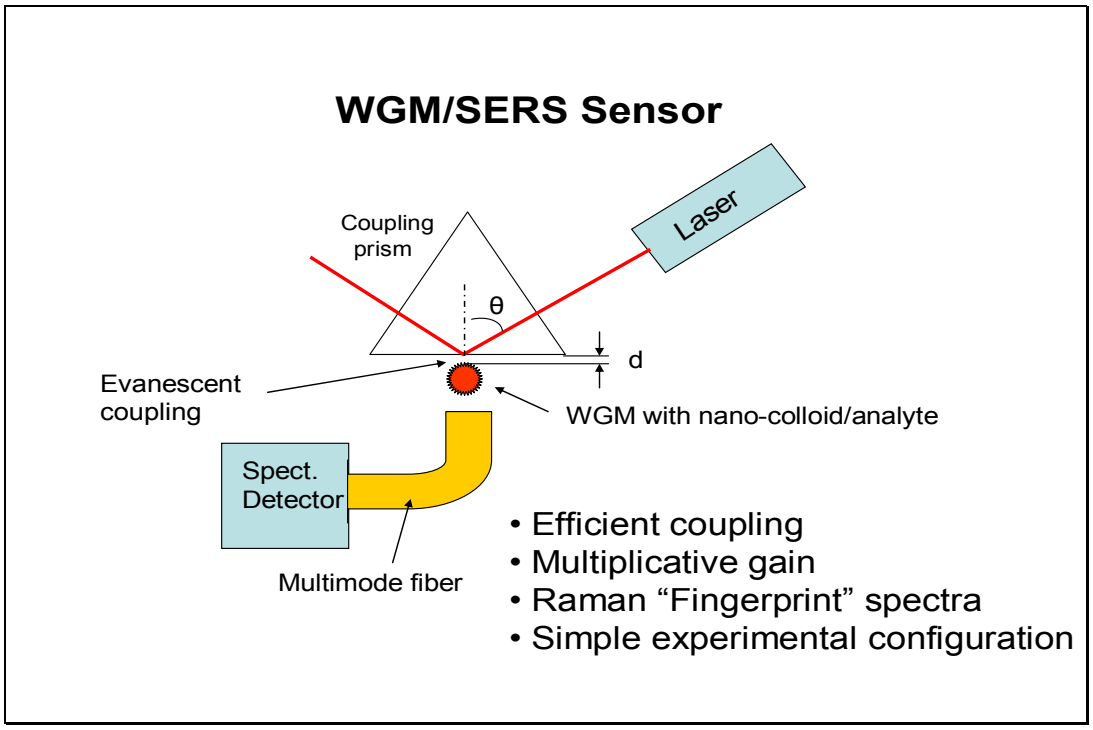

FIGURE 1

In order to investigate coupled resonance spectra, the microspheres are prepared with an approximately 20-30 nm layer of silver colloid particles doped with a suitable analyte; the microsphere is initially coated with a thin (monolayer) silane layer to facilitate bonding to the colloid and analyte. Colloid particles are fabricated in our laboratory using the well-known Lee-Meisel method. In this manner, Raman emissions from the analyte are efficiently coupled to both the WGM's of the microsphere and the surface plasmon-enhancecd (SERS) oscillations of the analyte, generating greatly enhanced coupled resonant (WGM/SERS) analyte spectra.

Experimental Results

The experimental arrangement illustrated in Fig. 1 was used to obtain WGM/SERS spectra from the well-known organic dye, Rhodamine 6G (R6G) and from a bacterium, E Coli. Spectra of the dye were used primarily as calibration spectra to provide a quantitative description of our spectral detection capability. WGM/SERS spectra depend on several experimental parameters including: (1) the distance s between the sphere and the prism, (2) the angle of incidence, A, of the laser beam (A greater than the critical angle for total internal reflection) and (3) the wavelength of the incident laser beam. Results of varying the first two parameters are presented here; experimental study of the third parameter awaits our acquisition of a tunable laser source. The effect of varying these two parameters on the WGM/SERS signal level are plotted in Figs. 2 and 3. Figure 2 shows the dependence of WGM/SERS signal on distance of the sphere to the coupling prism. Note the total distance traveled is less than 1 micron, consistent with evanescent coupling distances. Figure 3 shows the WGM/SERS signal as a function of the angle in excess of the critical angle. Again, the measured angle dependence in the 0.02-0.09 degree is consistent with the evanescent coupling variation of the angle of incidence. In particular, note the steep increase in signal level beyond the critical angle signifying the onset of highly efficient coupling in the evanescent region. The bar graph provides more quantitative data on the angular dependence of the evanescent coupling.

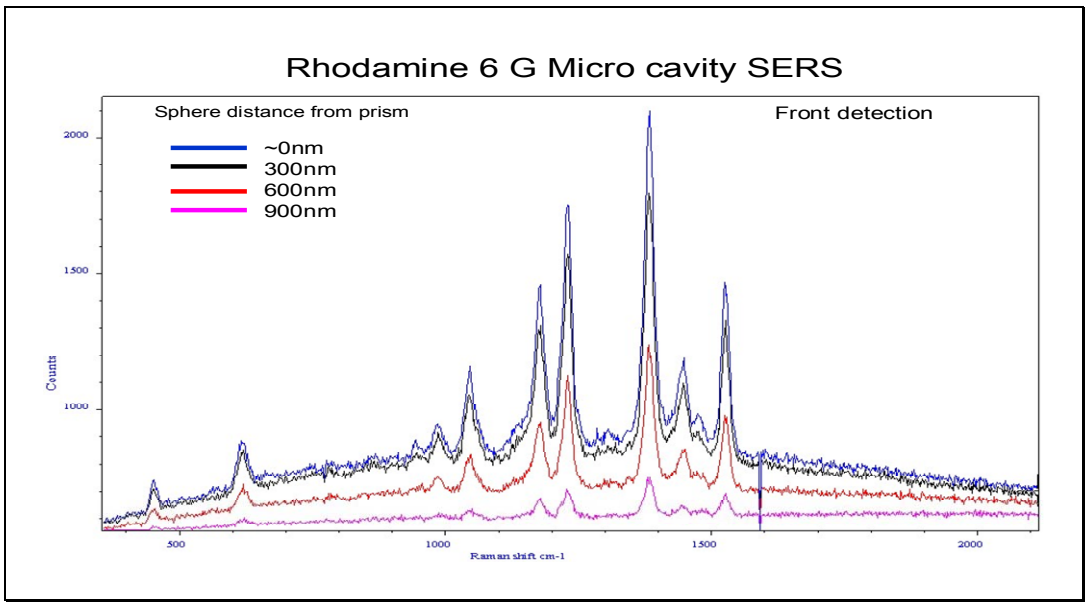

FIGURE 2

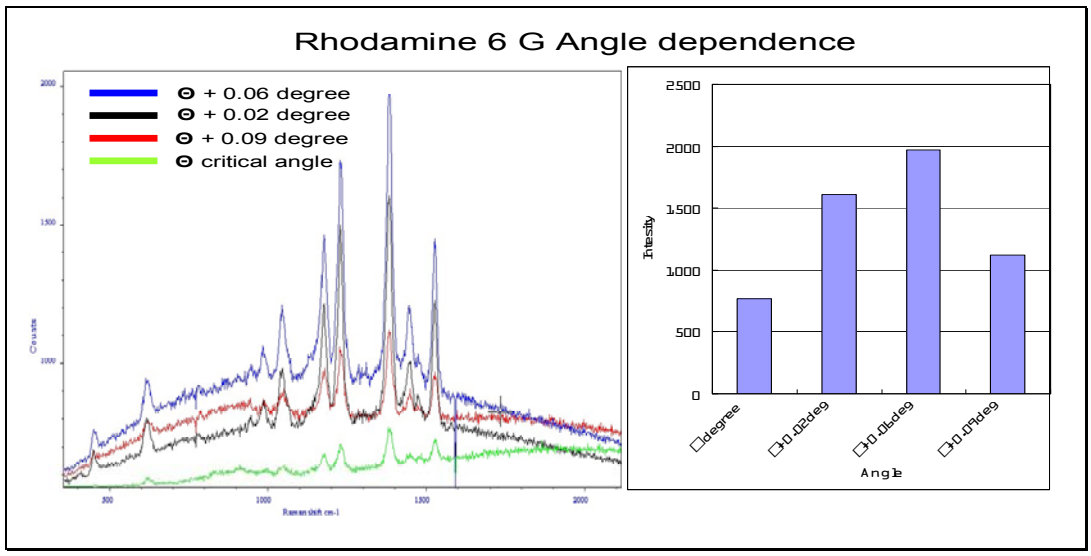

FIGURE 3

Figure 4 is a WGM/SERS spectrum of the e Coli bacterium. The feature of interest in the Figure is the great sensitivity of the measurement, corresponding to a small number of bacteria (1-5) in the pump laser focal volume and the short time to acquire signal (about 5 sec).

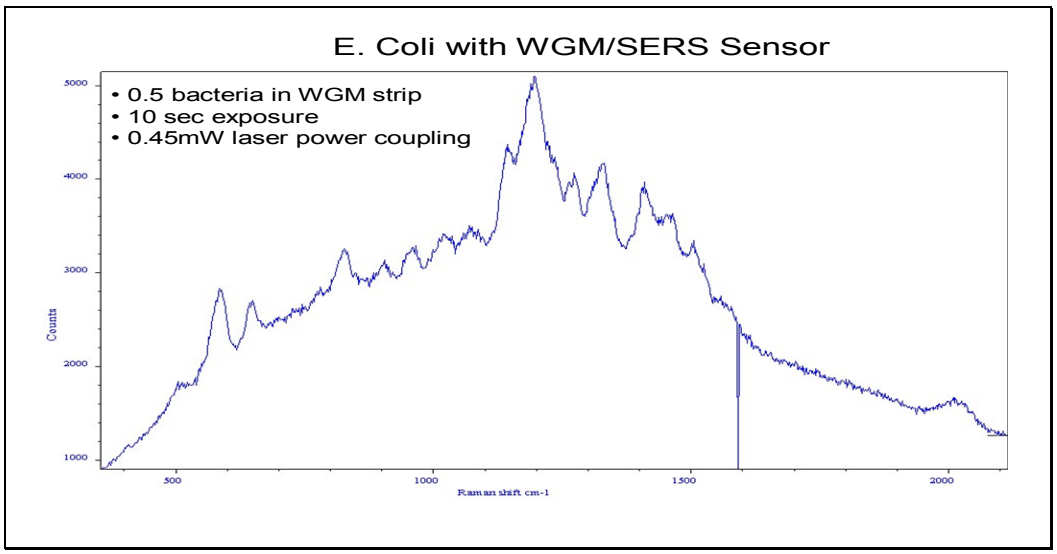
E. Coli with WGM/SERS Sensor
• 0.5 bacteria in WGM strip
• 10 sec exposure
• 0.45mW laser power coupling
Counts
5000
4000
3000
2000
1000
500
1000
1500
2000
Raman shift cm-1

FIGURE 4